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ABSTRACT

Although poor air quality in a school can have multiple causes, the heating, ventilating, and air-conditioning (HVAC) system plays a major role. Suggestions that architects, facilities managers, school board members, and administrators can use in selecting HVAC systems are discussed. Focus is on the performance criteria for classroom systems, and includes temperature and humidity ranges, indoor air quality, energy use, operation and maintenance, simplicity, staffing and standardization, reliability, flexibility, vandal proofing, and capital cost. Detailed descriptions of the kinds of systems used for classrooms are also discussed, such as the use of unit ventilators, variable air volume systems, single zone systems, multizone units, water source heat pumps, and separate ventilation air systems. The advantages of each of these systems are presented. Other considerations facing decision makers include choosing between mechanical or natural ventilation, and figuring ways in which building design, climate, and capital costs will affect such decisions. Likewise, school officials must consider the specifics of location, architecture, use, and management of the facility. To achieve the performance objectives of any HVAC system, requires a balancing of air and water flows, testing performance, documentation, and using trained operating personnel. (Contains five illustrations and nine references.) (RJM)

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ED 415 660

SELECTING HVAC SYSTEMS FOR SCHOOLS

TO BALANCE THE NEEDS FOR INDOOR AIR QUALITY, ENERGY CONSERVATION AND MAINTENANCE

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Introduction

Beginning in the 1970s many schools cut back on the supply of outdoor air, shortened heating, ventilating and air-conditioning (HVAC) system operating hours, changed classroom thermostat settings, and even added complex system controls in order to manage mounting energy costs.

As a consequence of these and other measures, the classroom environment suffered. Discomfort, even illness, has been attributed to poor indoor air quality. Some situations become so serious as to cause buildings to be vacated pending resolution of the problems. While poor air quality has multiple probable causes, HVAC system design, installation, maintenance and operation are major factors. Correction is often complex, time consuming and costly.

As a minimum, designers of HVAC systems must be guided by building codes and industry standards regarding ventilation rates and energy use. Capital cost budgets may limit the choice of system or its quality and inadvertently obscure the basic objective: *to provide a comfortable, healthy environment conducive to effective learning.* Accordingly, the purpose of this bulletin is the evaluation of criteria for the selection of HVAC systems and a comparison of their capabilities to meet this objective.

The bulletin is directed not only to the design engineers but the architects, facilities managers, school board members and administrators who often influence HVAC system selections.

The focus of the bulletin is the classroom for general instruction in primary and secondary schools. Both new construction and renovation to replace old equipment or to air condition existing schools for warm weather operation are discussed in this bulletin. HVAC systems serving areas such as science laboratories, art instruction, career and technology facilities must meet specific indoor air criteria. General classroom HVAC without modification may not be well suited for such spaces.

Control of asbestos fibers in existing buildings is not assigned to the ventilation system. However, the installation of some systems, such as those requiring ceiling ductwork or piping, could involve disturbance of existing asbestos containing building materials. This condition could become a major factor for system selection.

HVAC Objectives

The selection parameters listed below set performance criteria for classroom HVAC systems. The comparative ability to meet such criteria offers a basis for informed choice.

Temperature and Humidity

Maintaining space temperature and humidity within a comfortable and healthy range is a prime objective. The American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) Standard 55-1992, **Thermal Environmental Conditions for Human Occupancy,** defines comfort temperature and relative humidity conditions for both summer and winter. Seasonal clothing, solar radiation, level of activity, stress and productivity influence the level of comfort. A year round range of between 72 and 76F is generally acceptable assuming fairly uniform conditions throughout the classroom, with air motion in occupied locations within the space not above 30 feet per minute. Floor temperatures are of special importance in rooms serving young children. By insulating or heating the floor slab, a minimum of 72F for carpeted floors and higher if hard surfaces should be kept.

Maintaining the relative humidity between 30 and 60% is basically a health consideration. Above that range fungi and bacteria have been shown to produce rapidly. Above 70%RH, fungi growth can become a serious health risk. Conversely, respiratory irritation and aggravation of cold symptoms are a consequence of low humidity during cold weather. Some HVAC systems have humidifying capability, but this provision is rarely found in schools. During the year the moisture content of the outdoor air varies greatly. Its introduction for classroom ventilation or, when feasible, for cooling, requires superior HVAC system performance to control room relative humidity within desirable limits.

Indoor Air Quality

The concentrations of contaminants within the classroom are the result of emission rates from internal sources and the rate of dilution through the supply of relatively contaminant-free air.

Because the classroom in session has a high concentration of people, one producer of contaminants is the occupants themselves. Humans generate odors and through sneezing, coughing, and talking disperse microorganisms into the air. Building and instructional materials can emit volatile chemical vapors into the air. The latter source can be of special concern in art, career and technology education facilities. Materials for new construction and renovations should be selected for low emission characteristics. Renovations are best undertaken when the classroom is not being used for an extended period and with exhaust ventilation both during and following the work. Similarly, volatile cleaning solvents, interior paints, and pesticides (when essential within an integrated pest management program) should be applied only during unoccupied periods.

Dirty air conditioning system components enable microorganisms to grow in wet or high humidity locations, such as coils or drip pans. Spores, toxins and other contaminants are produced and become aerosolized. Regular maintenance and cleaning of these areas is crucial if good air quality is to be achieved. It is essential that HVAC components be selected for cleanability and accessibility.

Filters with an ASHRAE Dust Spot Efficiency (not Arrestance) of 25% or more can provide superior protection of HVAC components exposed to the air compared to the coarse fiber or metal filters typically furnished with manufactured equipment. Better filtration, more thoroughly discussed in another Maryland State Department of Education Technical Bulletin, **Air Cleaning Devices for HVAC Supply Systems in Schools,** can effectively remove airborne microorganism laden particulates, pollen and dust from the recirculated and outdoor air streams. Dust Spot efficiency in the range of 45 to 85% is preferred; however should equipment constraints preclude filters in this range, a minimum of 25% can almost always be applied.

The introduction of adequate outdoor air is recognized as an important HVAC system consideration. An outdoor air ventilation rate of 15cfm per person for general classrooms is prescribed by ASHRAE Standard 62-1989, **Ventilation for Acceptable Indoor Air Quality.** This value has been adopted by all three major USA model mechanical codes and is being incorporated into most state and local codes. In some instances this constitutes a three fold increase over previous requirements with the potential consequences of:

- Increased capital cost for heating and cooling capacity
- Increased energy use
- More difficult space humidity control.

Thoughtful selection of controls and equipment can minimize these consequences without unacceptable complexity. Heat recovery techniques can now be more effectively employed and may actually simplify the design.

Acoustics

Good speech communication is essential to effective teaching. Noise from equipment within the classroom, emanating from air outlets or radiating through ceilings, can be disruptive. The ASHRAE Fundamentals Handbook recommends a criterion for classroom sound of NC-30 as an acceptable system noise level for the range of speech communication frequencies. System and equipment selection along with application of sound attenuating techniques are the means of limiting HVAC system noise to acceptable levels. Internal duct lining for sound control should be limited to situations where other techniques are not feasible.

Energy Use

Construction projects can be assigned an energy budget, usually expressed in: BTU/Ft²/year. In Maryland, for example, 45,000 BTU/Ft²/year is considered a reasonable goal for elementary schools. Some school

designs incorporate heat recovery and other energy saving features that virtually overcome the burden of increased outdoor air. The following concepts offer opportunities.

- Demand-controlled ventilation: Ventilation is prescribed based on the number of occupants. When occupancy is reduced or discontinued the outdoor ventilation air supply can be reduced accordingly (unless other internal sources require dilution). Carbon dioxide controllers are being applied to account for occupancy and to regulate outdoor air flow to limit CO^2 concentrations to 1000ppm or less. Such controllers commonly require regular recalibration and performance checks — tasks that require trained specialists. Actually, where the hours of occupancy for a classroom are predictable similar results can be achieved through a timed program control.
- Energy recovery: Thermal energy use can be reduced through transfer from exhaust air to the outdoor ventilation supply. Some methods involve little, if any, additional maintenance burden. In humid climates, thermal energy can also be effectively transferred from the entering outdoor air to the supply air downstream of the cooling coil to save energy for both cooling and reheat needed for space humidity control.
- Equipment selection: Selection of all HVAC energy using components for optimum efficiency takes on improved economic justification.

Operation and Maintenance

Improper operation and neglectful maintenance have been identified as major causes of poor indoor air quality. HVAC system requirements must be matched to the training and capabilities of the school district staff. More likely the level of training and capabilities of the maintenance staff will require upgrading to meet the requirements of a system that adequately supports the environmental requirements of the classroom. Here is an important matter for communication between district facilities management and the designers. The overriding basis for HVAC system selection may be past experience and familiarity with a particular system. Valid reasoning no doubt, but it should not be a barrier that inhibits considering concepts offering a more effective classroom environment.

Simplicity

As performance demands for systems increase, it becomes a constant struggle to keep controls and other elements as uncomplicated as practicable for the operators and maintainers to manage.

Staffing and Standardization

Knowledge of the staffing organization as well as standardized procedures and procurement practices for operation and maintenance can aid designers in system and component selection. For example, filter types may be standardized for bulk purchasing or replacement subcontracting.

Reliability

Reliable performance hinges on equipment maintenance, component life, accessibility and cleanability. Designs placing air conditioners above ceilings, or on inaccessible roofs may result in space savings, but invite inadequate maintenance. Provisions for cleanability sometimes cost more, but pay dividends in maintenance, performance, and equipment life. Consider:

- Doors (not screw-held panels) for access to HVAC components and intake screens.
- Sloping drain pans that minimize breeding places for microorganisms.
- Accessible coils.
- Accessible, efficient filters with tight sealing frames that not only protect occupants but really keep heat transfer surfaces clean.

Preventive Maintenance

Some systems will require more routine maintenance than others by virtue of type and number of components. Regardless of system type, well-planned, documented, regular maintenance procedures should be an integral part of any IAQ/Energy program.

Automation and Monitoring

In an age when electronic technology has an ever increasing presence in the classrooms, automated direct digital control, possibly with off-site monitoring, is likely to be a preferred choice.

Flexibility

Ability to meet changes in classroom usage or function will differ among systems and could be a significant factor in system selection. Flexibility to air condition only a portion of the classrooms and not the entire facility may also be significant. Some systems are more readily expandable to accommodate future growth.

Vandal Proofing

Protection against damage by vandals is a design consideration. Passive protective measures are more readily accomplished with some systems than with others — under window units, for example, are vulnerable and must be constructed and maintained to resist abuse.

Capital Cost

First cost is inevitably a strong determinant in system and quality selection. Budget decisions however should be based upon solid value judgements. Teacher and student performance can't be measured in dollars. Investment to reduce absenteeism, improve the learning environment and avoid future IAQ problems is sound. Component life expectancy, operating costs, and space requirements must be evaluated along with initial cost to better compare systems. Poor HVAC performance may actually have its origin with setting the capital budget too low.

HVAC Systems For Classrooms

Systems employed for classrooms are described in this section along with their perceived advantages and shortcomings. The evaluations are intended to serve as a guide during the decision making process of future project designs.

Unit Ventilators

Unit ventilators have long been the most popular method of heating and ventilating, and later for cooling of school classrooms. Basic components include outdoor and recirculating air inlets with automatic dampers, filter, heating and cooling coils and fan section. Except in warm weather, cooling is accomplished by blending outdoor and recirculated air. The outdoor air damper has an adjustable setting to supply not less than the amount required for ventilation. The heating source is commonly a hot water distribution system or electric resistance coils. Cooling is delivered by a chilled water distribution system or an integral refrigeration unit. A room thermostat controls both heating and cooling. The outdoor air damper closes to minimum position when cooling with refrigeration. The water distribution systems are often combined into a dual temperature system supplying chilled water during cooling and hot water during heating. System changeover can be manual or automatic. Unit ventilators are usually located at the outside wall beneath a window, but may be ceiling mounted.

Favoring the unit ventilator system are the following attributes:

- Developed specifically for classroom use with appropriate ruggedness and aesthetic features.
- No recirculation of air between classrooms — a requirement by some jurisdictions.
- Independent classroom control and operation.
- Effective room air distribution capable of offsetting downdrafts at a cold perimeter wall.
- Constant volume air flow.
- Duct work and central air handling equipment unnecessary.
- School maintenance personnel usually familiar with the system.
- More energy efficient than most other systems.

- Comparatively easy method to condition existing schools.
- Reliability — one inoperative unit does not affect the entire system.
- Easy to plan for future additions.

On the negative side:

- Controls for heating, cooling, economizer and ventilation are required in every unit.
- Relative humidity is not directly controlled, but a consequence of space temperature control. Humidity can rise above 60%, even 70%; a condition exacerbated by the increased outdoor air ventilation rate. This condition could be overcome by employing a space humidistat and a four pipe water system or resistance heaters to enable simultaneous heating and cooling. However, these measures entail increased maintenance and energy use.
- Excess outdoor air may blow in during cold windy weather through the intake causing drafts and risk of coil freezing.
- Condensed moisture must be conveyed to a disposal point. The wet components are potential microorganism growth sites.
- Filters are limited to one inch thickness. Although more efficient types can be applied, units are supplied with low efficiency coarse fiber or metal mesh media filters.
- Unit noise contribution is likely to result in NC35 or 40. Expect self contained refrigeration type units to be noisier.
- Maintenance is decentralized and normally performed in the room. Best scheduled when classes are not in session.
- Unit components are difficult to clean.
- Relief of air from the building is needed to avoid overpressurizing the building when the units are delivering large quantities of outdoor air.
- Outdoor air flow must be balanced for each unit to assure proper ventilation.
- Classroom space, roughly 1 to 2%, must be dedicated for floor mounted units.
- More adaptable to perimeter than interior classrooms. Other type systems are often employed for interior space service.
- Air flow can be obstructed by objects placed atop the units.

Variable Air Volume

Variable air volume (VAV) systems have probably become the second most frequently selected system. School design trends toward greater compactness have influenced its popularity because of its applicability to both perimeter and interior space. Both recirculated and outdoor air for ventilation and cooling (when outdoor temperature permits) are blended, filtered, cooled, and sometimes heated and humidified in an air handling unit serving multiple spaces. Supply air is ducted to room terminals that regulate the rate of supply air flow to the space served under control of a room thermostat. Intrinsically a cooling only system, it may also provide heat through terminal-located heating coils. Some terminals also have fans to recirculate air to maintain a constant or near constant supply of air to the room. The recirculated air is sometimes filtered to remove particles from the room air. Air is supplied to the room through registers or diffusers located high on the walls or in the ceiling. These devices must be selected to distribute effectively over the entire range of air flow. Minimum air flow is set for not less than the outdoor ventilation rate.

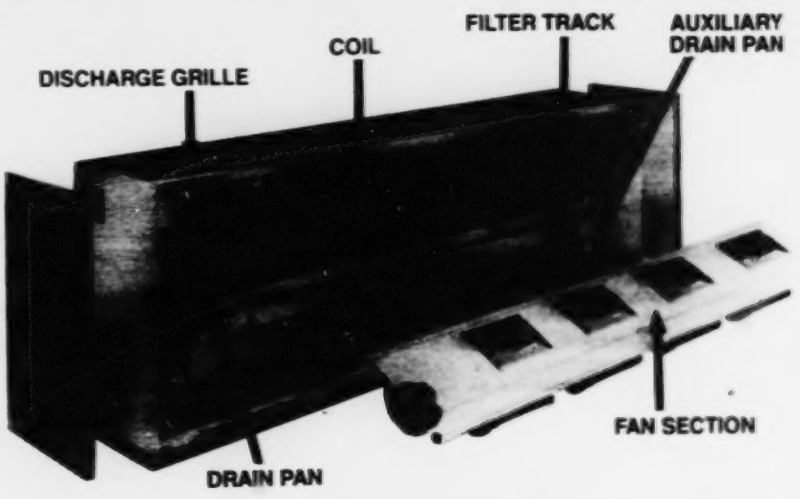


Figure 1. Unit Ventilator Construction

Features favoring VAV for classroom air conditioning include the following:

- Cooling, dehumidifying and filtering accomplishable at a central location. No need for such equipment in or adjacent to the classrooms.
- Medium or high efficiency filters can be applied.
- Both interior and perimeter building spaces can be supplied by a common system.
- Efficient. Less fan and reheat energy is needed than with constant volume systems. Energy use could rival unit ventilator systems depending upon application specifics.
- Except for room thermostats (which for all systems must be protected from abuse), all components can be remote and secure from unauthorized tampering.
- Outdoor air supply can be automatically adjustable to compensate for changes in total supply air flow and building population.
- Air distribution is readily adaptable to physical space changes.

Consideration of VAV must also appraise these shortcomings:

- Unless terminals are fan powered, supply air is below design for much of the school year. Air and uniform heat distribution to the classroom could be marginal at reduced flow.
- Mandated ventilation air flow to the classroom supplied to all spaces at a common temperature could cause overcooling unless terminal heaters are provided.
- Classroom relative humidity is not directly controlled, but a consequence of the dehumidified air supply rate to the room.
- Maintenance of terminals, if located above classroom ceilings, can be difficult. Neglect could result.
- Fan powered units above ceilings can radiate objectionable noise. May require shielding or location above adjacent corridor.
- Terminal fans can impair energy efficiency of system.
- All spaces, even though unoccupied, connected to a common system must be conditioned.
- Accessible acoustically isolated space must be allotted for central air handlers.
- Air distribution ducts take ceiling space. Installation in existing buildings may involve costly renovation and disruption.

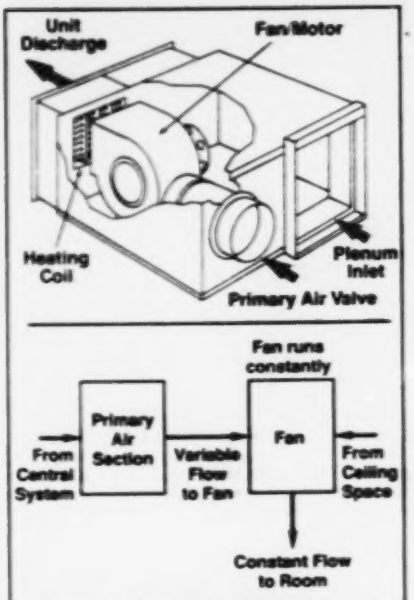


Figure 2. Series Flow Fan Powered VAV Terminal

- Expandable only if planned for with initial capital outlay for the provision.
- Performance reliability for an entire facility may depend upon the working order of one or a few components.

Single Zone Systems

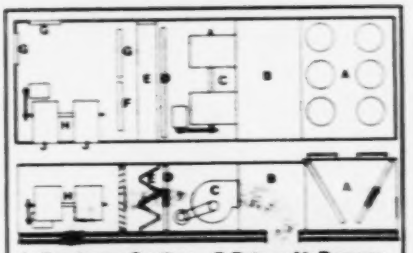
A single air conditioning unit located near the spaces served, often on the roof above, usually conditions one classroom. The unit can be factory built with integral air cooled refrigeration and compact for ease of installation. For schools such equipment should be heavy duty, institutional quality, not light duty, commercial. Supply air flow to the classrooms is constant. Supply air temperature is varied by the room thermostat. A heating coil within the unit makes it a year round system. An HVAC concept employing single zone and, to a lesser extent, multi-zone units are best suited to smaller schools or large ancillary spaces, such as a gymnasium.

Advantages of single zone systems include:

- First cost is often less than other systems for smaller schools.
- Central refrigeration, and possibly boiler plants, may prove unnecessary.
- Medium efficiency (30 to 60% ASHRAE Dust Spot) filters can be selected.
- A readily expandable approach: it may be the best option when unexpected expansion needs arise to augment other system types.
- Except for room thermostats, all components can be remote and secure from unauthorized tampering.
- Constant volume air flow to the classroom.
- Automation with centralized performance supervision can facilitate operation of remotely located systems.

Disadvantages include:

- For larger facilities, especially those with more than one floor level, the space needs for units and connecting ducts may prove impractical.
- Control of cooling by the room thermostat is usually on-off. Dehumidification ceases during the off cycle, moisture on the cooling coil re-evaporates. The relative humidity in the space is no longer controlled and can rise well above acceptable limits.
- Accessibility and acoustical control are easily overlooked design considerations. Roof top installation may make access difficult and can be a source of unacceptable noise vibration, and roof leaks as a consequence of maintenance traffic.



A. Condenser Section
B. Heating Section
C. Supply Air Fan
D. Cooling Coil
E. Filter Section
F. Return Air Damper
G. Outdoor Air Damper
H. Exhaust/Return Fan
J. Exhaust Air Damper

Figure 3. Roof Top Air Conditioning Unit

- Heavy snow can restrict maintenance and block air intakes to roof mounted equipment.
- Appearance of multiple roof top units can be objectionable.
- Refrigeration is likely to be less efficient than central chillers.
- While first cost frequently favors electric resistance heating to avoid the cost of heating plants and extensive water distribution piping, a high energy cost may be incurred.

Multizone Units

Whereas the single zone unit best serves only one classroom, multizone, though also frequently packaged with air cooled refrigeration and heating for roof mounting, can serve a half dozen or more rooms. The supply to each is divided into two or three alternative ducted pathways or "decks" equipped with automatic dampers that respond to the zone thermostat to bypass the cooling coil to regulate the zone temperature. A coil in the bypass, or in each zone supply, provides heating. A third deck, a feature of some designs, separates the cooling and heating functions to prevent simultaneous heating and cooling (but reduces the capability to limit space relative humidity). With the cool air supply closed, air is controlled to flow through or bypass the deck heating coil. A separate supply duct distributes air from the unit to each zone served.

Attributes are similar to those listed for single zone systems; however,

- First cost can be lower than single zone for clusters of classrooms.
- With fewer units needed compared to single zone, acoustical, maintenance and aesthetic concerns are more manageable.
- Temperature control can be proportional for both heating and cooling.
- With reduced cooling, part of the air continues to be dehumidified by the cooling coil, providing indirect regulation of space humidity superior to that afforded by single zone units.

On the negative side:

- With a separate supply for each classroom, ductwork can become extensive, both costly and space consuming.
- Inflexible for accommodating space change or expansion.
- Two deck designs may involve the need for reheat to control room temperature, reducing energy efficiency.

Water Source Heat Pumps

Each classroom is served by a water source heat pump containing a reversible refrigeration unit. For cooling, air is circulated through the refrigerant chilled coil. Heat is rejected into a closed loop water distribution system from which it is typically removed through heat exchange to a cooling tower and expelled to the atmosphere. To heat the room, the refrigeration cycle is reversed. Air is heated by the refrigerant coil with heat withdrawn from the water system. A conventional boiler makes up heat to the water as needed. If some units require heating while others cooling, thermal energy can be transferred through the water loop thereby conserving energy. Heat produced by lights and people in classrooms that require cooling is transferred through the loop to others calling for heating. Outdoor ventilation air may be introduced through the unit or a separate system as discussed on page 6. Unit ventilators employing water source heat pumps are also available.

Advantages of a water source heat pump system include:

- Heating or cooling for each space is available year round.

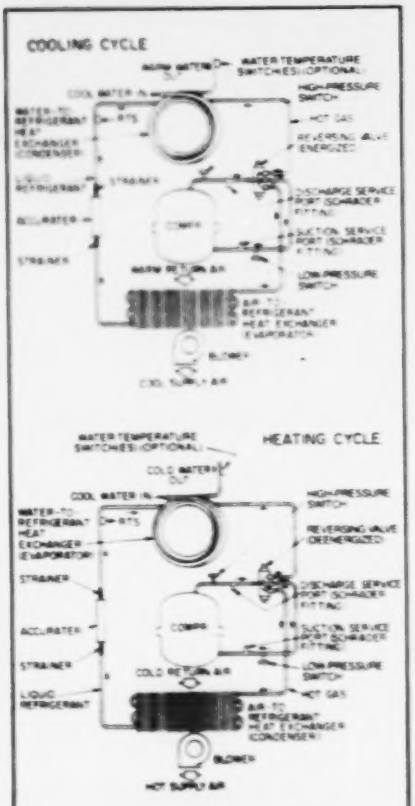


Figure 4. Water Source Heat Pump Flow Diagram

- Changeover occurs at the classroom either manually or automatically.
- Energy efficiency. The energy transfer feature may supplant the need to supply outdoor air for cooling as described under "Unit Ventilators" with its attendant controls and potential problems.
- Location of the classroom unit is flexible. If outdoor air is unnecessary for cooling, it need not be at the perimeter wall and may be used for interior space as well as perimeter classrooms. Ventilation (outdoor) air can be ducted to the unit or supplied separately.
- Units can be serviced in place or replaced with a spare using quick disconnect piping and electrical connections.
- Supply air rate is constant. Units suitable for "closet" locations can be equipped with medium efficiency filters.
- Closet location can reduce noise in the classroom.
- Water circulation loop can serve cooling or heating only units as well as heat pumps.
- No pipe insulation normally needed since water ranges between 65F and 90F.
- Central refrigeration, and possibly boiler plants, not needed.

Disadvantages include:

- Most units are not designed to heat or cool large proportions of untempered outdoor air. Preconditioning of the outdoor ventilation air is usually necessary for unit operation.
- Space temperature control is "on-off." Introduction of outdoor air without preconditioning can cause undesirable humidity levels.
- If located directly in the room, or above an acoustically transparent ceiling, sound criteria objectives will not be met.
- Space must be allotted for the classroom units. Above-ceiling locations are a poor choice considering maintenance difficulties and potential condensate leakage.
- Moisture removed from the air must be conveyed to disposal point.
- Wet surfaces within the units are potential growth sites for microorganisms.

Separate Ventilation Air System

This approach is being applied to overcome indoor air quality problems and to upgrade existing systems to current standards. Outdoor air — filtered, heated, cooled, dehumidified, humidified — in a central air handling unit is supplied by ductwork to the classroom either through the unitary equipment or through ceiling diffusers. Air flow may be constant or under demand control. Air temperature and moisture content is common to all spaces. Except as needed for pressurization, and exhaust makeup, the air introduced is relieved.

Such a ventilation supply can be designed to work in concert with unit ventilators, fan coil units (a unit ventilator without the free cooling feature), or water source heat pumps to overcome some of the shortcomings of those systems. Proper control of classroom humidity is readily accomplishable by the ventilation system.

In cooler weather much of the free cooling is performed by the ventilation system. This feature of room units becomes dispensable. Other benefits of the supplemental ventilation supply for classrooms served by classroom units are:

- Reduced maintenance.
- Smaller, quieter, less expensive classroom units.
- Superior humidity control.
- Cleaner room air.
- Cleaner unit components.
- Reduced condensation on the unit cooling coil.
- Assured delivery of cleaned outdoor air ventilation rate.

Mechanical and Natural Ventilation

Natural ventilation can be both energy efficient and pleasantly stimulating.

When natural ventilation is employed to supplement mechanical ventilation, the combination offers an alternative to complete air conditioning. The mechanical ventilation system can be designed to deliver the appropriate supply of filtered outdoor air through unit ventilators or a ducted central air supply. Space heating for winter room temperature control can be an integral feature of the mechanical system. Natural ventilation can supplement the mechanical system to provide improved thermal comfort during moderate weather and heat relief during warmer conditions. Even though this combination does not offer complete year round management of temperature and humidity, its simplicity, ease of maintenance and low capital and operating costs, compared to the systems of air conditioning previously described, justify its consideration for many school projects. In fact, the mechanical system could be designed to permit the future addition of cooling for complete air conditioning.

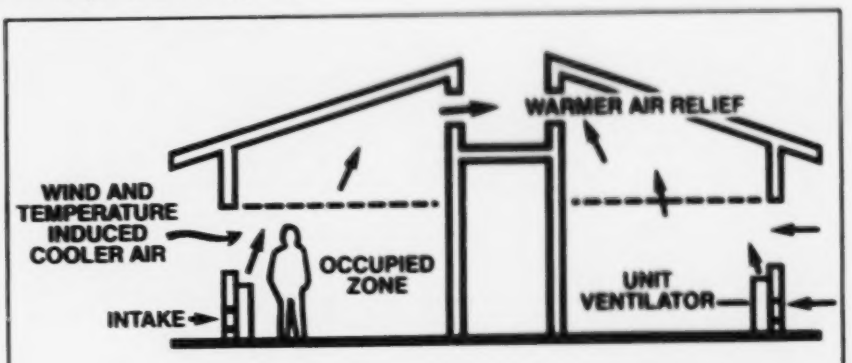


Figure 5. Mechanical Ventilation Combined with Natural Ventilation

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Building Design Considerations

Natural ventilation utilizes the wind on the building facade creating areas of positive and negative pressure and causing movement of air into and through the building. In addition, temperature differences between inside and out cause warm air to rise and escape from a building to be replaced by cooler, denser outdoor air. Physical barriers to air flow between floors and other fire compartmentation for occupant safety can limit both wind and temperature induced ventilation and cross flow. Where permissible, internal partitions that could seriously impair cross circulation should have fixed or adjustable openings. Nonetheless, buildings can be designed to take full advantage of natural ventilation with these two principles of air flow in mind.

Outdoor air enters through windows and other openings in the exterior wall. Building codes generally require mechanical ventilation or specify openings to the exterior in the amount of 4 or 5% of the floor area to permit natural ventilation.

Such openings are best located in the "occupied zone," below average head height. Intake openings should be matched by exhaust openings of equal or greater size. High perimeter to floor area ratios take full advantage of the wind induced pressure differentials. Although ventilation induced by temperature differentials is limited in one story school buildings with inherently low building height, high ceilings with relief vents near the peak can utilize thermal stratification. Warm air relieved from the room is replaced by cooler air entering at the occupant level. Removal of stratified hot air can be accelerated by mechanical exhaust. One approach: an attic fan drawing air from multiple rooms below through ceiling vents, lowering the attic temperature and reducing heat gain to the rooms. Windows, ventilating sash, and other openings in the exterior walls should be selected to minimize drafts on occupants seated nearby. They must be capable of adjustment and tight closure.

Siting and configuration considerations of the school can enhance the effectiveness of natural ventilation.

These include:

- Orientation of major facades toward prevailing summer winds.
- Exterior exposures for all occupied spaces.
- Exterior openings on opposite faces of the building, where feasible, to create cross circulation.
- Limited building depth.
- Optimum use of natural lighting to minimize internal heat gain.
- Building and landscaping features for external sun shading.

Other design considerations entail:

- Noise: Avoid the intrusion of noise through wall openings from traffic, industrial processes, air cooled condensers or the kitchen.
- Insects and other pests: Screen to prevent the entry of insects, birds and rodents.
- Security: Protect ventilation openings to safeguard the building.
- Housekeeping: Avoid natural ventilation wherever dust-free environments are vital, as in computer rooms.
- Outdoor air quality: Avoid intakes in proximity to industrial process venting, urban traffic, and building exhausts. These pose threats to health as well as comfort (odors). Even in rural locations, odors from animal wastes and fertilizer can cause seasonal annoyance.

Climate

Climate and other local conditions could limit the use of this combination of mechanical and natural ventilation as may the suitability for teaching during summer sessions. However, natural ventilation can provide cooling even in hot, humid climates. Its effectiveness is reduced when the wind speed is under 5 miles per hour as might occur if the wind is retarded by nearby structures. In hot, arid climates (less than 20% relative humidity) the dry air could cause discomfort and dehydration.

Regional information is available from the National Oceanographic and Atmospheric Administration regarding average and extreme temperatures, wind direction and speed, and relative humidity. Generally, wind patterns in North America are from northwest to southeast in the winter, and from south to north in the summer. Winter wind speeds are higher and more consistent than summer winds, which tend to be gentle breezes. Topography, vegetation, or nearby land development can materially affect the movement of air at the building site.

Economic Evaluation

Capital costs considerations: While significant mechanical cost savings are likely compared to air conditioning, provision for natural ventilation may restrict freedom of building placement and configuration. Some additional construction cost may be incurred if the building shape needs to be narrower and less compact, thereby requiring more extensive exterior walls, longer mechanical distribution systems, and increased heating loads.

Operating Costs: Lower costs for substantially simplified mechanical maintenance and energy usage should be factored into anticipated capital cost savings for a more complete economic evaluation of the savings obtainable from the mechanical/natural ventilation concept.

Selecting the Appropriate System

Objectives for classroom HVAC relate to specifics of location, architecture, use and management of the facility. Selection starts with a comprehensive list of those objectives, including costs. Capital costs for the HVAC systems described depend upon many factors relating to the school design and its location.

Systems employing factory built equipment packages containing air handling, heating and refrigeration components are likely to cost less than those with central heating and cooling plants, but are generally considered to have shorter life spans. However, generalized comparisons can be seriously misleading. Only comprehensive cost estimating expressly for the specific project can offer adequate guidance. To initial value of all pertinent costs relating to site, design, and construction, add the estimated present worth of operating and replacement costs for a complete economic perspective. Other methods of combined life cycle cost evaluation are valid and may be preferred.

Systems incorporating an outdoor air ventilation supply to complement classroom units can offer superior classroom air quality. Such systems may add to the first cost, but reduction in the room unit costs may reduce the significance of any premium. Faced with an increased ventilation criterion and the consequent prospect of higher energy cost, energy conservation measures that do not compromise the environmental qualities of the classroom can be viewed with a fresh perpective. For instance, complementary ventilation systems that effectively transfer energy between incoming outdoor and exhaust air are being applied for classroom service.

With thorough evaluation, the appropriate concept for selection can be achieved. What can go wrong? A budget set too low for the results expected? Resistance to change? Poor communication? Inexperience? One way to avoid these pitfalls is through open collaboration among administration, facility management and the design professionals during concept determination and the ensuing phases of design development.

Building Commissioning

To achieve the performance objectives of any ventilating or air conditioning system, a contract for comprehensive commissioning of the system by a competent agency is recommended to:

- balance air and water flows.
- verify performance by testing.
- assure complete documentation.
- train operating personnel.

IAQ investigations all too often identify improper air and water balancing and failure to performance test automatic controls as contributory causes of serious deficiencies.

Illustration Credit

Figure 1. Trane Company
Figure 2. Titus
Figure 3. Trane Company
Figure 4. Carrier Corporation

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